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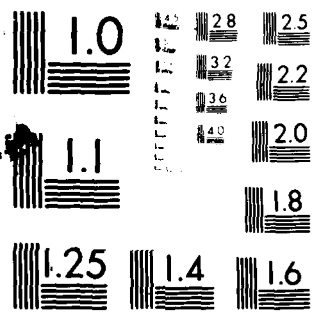
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Review 2-81

AEROMEDICAL REVIEW

ASSESSMENT OF POSSIBLE HAZARDS ASSOCIATED WITH APPLICATIONS OF MILLIMETER-WAVE SYSTEMS

David N. Erwin, Ph.D.
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November 1981

Approved for public release; distribution unlimited.

USAF SCHOOL OF AEROSPACE MEDICINE
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This technical report has been reviewed and is approved for publication.

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This review examines the characteristics of millimeter-wave radiofrequency radiation, predicts possible exposure levels, and analyzes the millimeter-wave bioeffects literature. Data gaps and possible mechanisms of millimeter-wave bioeffects are examined.

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PREFACE

Current research and development are placing increasing emphasis on the millimeter-wave (MMW) frequency region (30-300 GHz) of the electromagnetic spectrum. Among new applications are radar, surveillance, communications, designation, guidance, and sensing systems. As with other radiofrequency radiation (RFR) systems, the Air Force must periodically review the development and application of these devices and assess whether their application poses any hazard to Air Force personnel and/or the public.

This document discusses four aspects of Air Force use of millimeter waves. First, present and projected devices described in terms of the physical properties and operational parameters of model systems. These properties are used to calculate the ranges in which specific power densities might be encountered. Second, the RFR bioeffects literature relevant to these systems is summarized and examined from the standpoint of established biological endpoints, the threshold exposures for any effects, and the possible significance of the effects for human health and safety. Third, the adequacy of current Air Force safety precautions is assessed on the basis of the above. Finally, identified data gaps are listed, together with recommendations for filling those gaps.

An independent review of the bioeffects literature in this area constitutes the detailed body of bioeffects literature for this paper. The literature was reviewed by seven researchers preeminent in various fields of biological and millimeter-wave research under USAF contract F33615-79-C-0614 with the University of Utah.

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ASSESSMENT OF POSSIBLE HAZARDS ASSOCIATED WITH APPLICATIONS OF MILLIMETER-WAVE SYSTEMS

INTRODUCTION

The ensuing sections of this document will show the following to be true:

1. Some millimeter-wave systems may be expected to produce relatively high power levels (>10 mW/cm^2) at some loci in the beam, especially with the development of new high-power hardware technology.

2. Millimeter-wave bioeffects research is a complex field of sometimes contradictory results. Complications in this area are increased by several factors, such as inherent experimental difficulties with MMW equipment, inadequate definition of proper experimental procedure, and insufficient detail in reports of many experiments.

3. At present no replicated bioeffects are attributable to MMW radiofrequency radiation (RFR) except those due to heating of the sample. Several possible mechanisms of low-level effects have been proposed, and some reported for bacterial or cell-culture systems, but none has been substantiated by replication in whole-animal experimental work.

Current Air Force regulations and ANSI guidelines appear appropriate. However, this situation may change, and exposure of personnel should be minimized wherever possible. *In no case should the current guideline of 10 mW/cm^2 or 3600 $mW\text{-}sec/cm^2$ in any 6-minute period be exceeded.*

The USAF School of Aerospace Medicine (USAFSAM) will continue to monitor the burgeoning area of MMW bioeffects research and to invest in research deemed important to Air Force applications. These efforts depend upon insights gained from other Air Force activities. For this reason, USAFSAM will make every effort to respond in a timely manner to queries from laboratories and program offices dealing with new systems and applications.

MILLIMETER-WAVE SYSTEMS

The systems of concern are emitters with frequencies between 30 and 300 GHz. At present, applications tend to be concentrated in the lower portion of this spectrum.

Characteristics of Model Systems

For purposes of analysis, we used model systems to calculate estimates of power density distributions around the emitters. Each system under development or testing must be evaluated for specific safety considerations. The models chosen consist of either a 10- or 20-cm parabolic dish antenna with either a 1- or 6-degree beam width. Since present systems use low average-output power levels, our calculations are based on an estimate of 1-W average power output. The calculations would apply equally for a system producing 1-kW peak power with a .001 duty factor, although other considerations must be introduced for peak powers (see DISCUSSION). Computations of the average incident power density (PD) at a given distance (d) from the antenna are dependent upon whether that distance is within the so-called near field, far field, or transition regions of the antenna propagation pattern. These regions are defined as follows:

$$\text{Near field: } d < L^2/\lambda$$
$$\text{Far field: } d > 2L^2/\lambda$$
$$\text{Transition: } L^2/\lambda \leq d \leq 2L^2/\lambda$$

where L is the largest dimension of the emitting antenna and λ is the wavelength. A diagrammatic representation of the models is shown in Figure 1. The values of dn (near field distance = L^2/λ) are shown as functions of frequency or wavelength and antenna size in Figure 2.

Computed Power Density Boundaries

For the far-field of the model systems, PD estimates were calculated by assuming that the average output power (W) is confined to the conical volume defined by the beam width (θ), and obeys the inverse square law:

$$PD = W/(\pi(d \times \tan(\theta/2))^2) \qquad \text{where } d > 2L^2/\lambda.$$

For the near-field of the system, the PD estimates were calculated by assuming that the average output power is confined to the cylindrical volume defined by the face of the parabolic reflector and the bore sight axis:

$$PD = W/(\pi \times (L/2)^2) \qquad \text{where } d < L^2/\lambda.$$

For the transition region ($L^2\lambda \leq d \leq 2L^2/\lambda$), the PD is assumed to be a linear extrapolation between the other two cases. That is,

$$\text{from } PD = W/(\pi \times (L/2)^2) \qquad \text{at } d = L^2/\lambda$$

$$\text{to } PD = W/(\pi \times ((2L^2/\lambda) \tan(\theta/2))^2) \qquad \text{at } d = 2L^2/\lambda.$$

Figures 3-6 show the results of these calculations for each model system, based upon a 1-W average output power. We must emphasize that these estimates are based on the assumption that all side-lobe power is confined to the main beam and that power is uniform within the beam. Also assumed is that there is no substantial reflected component to the power density, an assumption that should be checked in an enclosed area or high-clutter environment. Note that the distances at which 10 mW/cm^2 might be measured occur only in the vicinity of the 4-inch (10 cm) parabolic dish. Implications of these power density levels will be discussed later. Further information and references for the above calculations can be found in Durney et al. (78).

A program to calculate these power density values was written in "BASIC + 2" to run on a DEC PDP-11 computer system. The computer program is included as Appendix A so that others may compute PD ranges for specific systems. A more refined calculation, written in "FORTRAN IV-PLUS" for the PDP-11, is in use at USAFSAM/RZP and USAF OEHL.

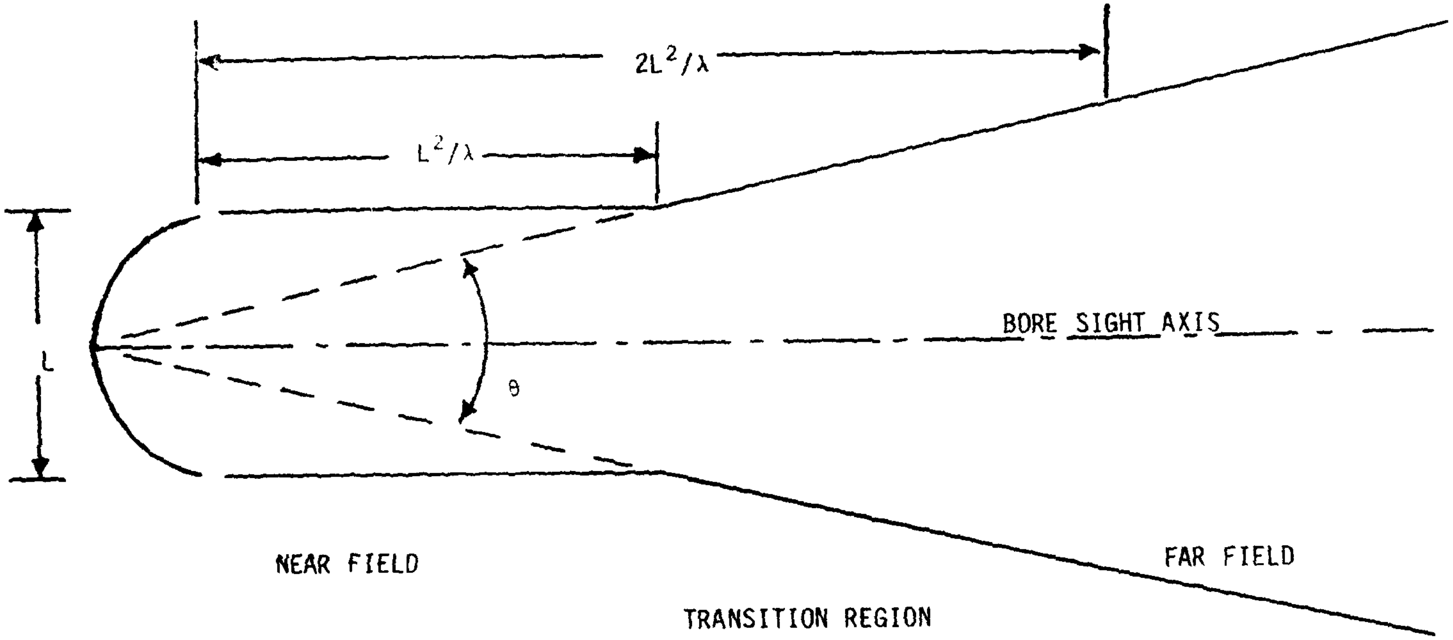

Figure 1. Geometry of *millimeter-wave* model systems. In the near field, the total output power is assumed confined to the cylinder of *diameter* L and length L^2/λ. The far field is assumed to obey the inverse square law, *and* the transition *region* is assumed to linearly change from the near- to far-field values.

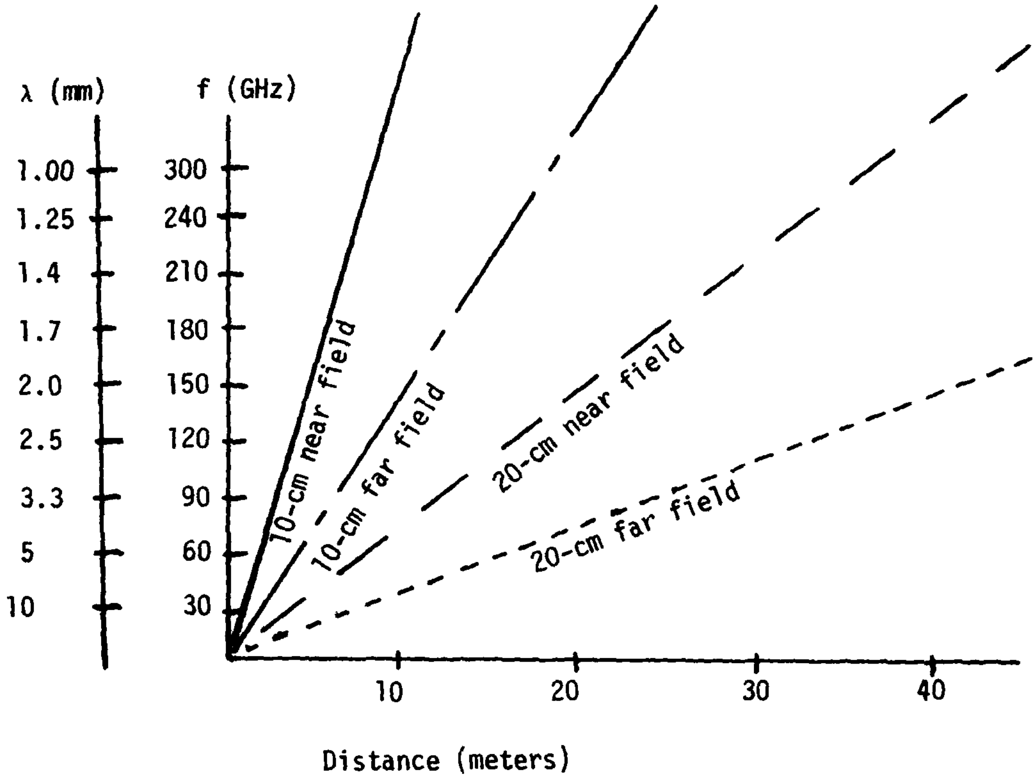

Figure 2. Near- and far-field boundaries. Curves represent the frequency (or wavelength) dependence of the near- and far-field boundaries for each antenna size. For example, at 3.3 mm (90 GHz) the far field of a 20-cm antenna begins at approximately 25 m from the dish.

Future Systems

Developmental efforts and basic research are underway in both DOD and commercial laboratories to develop high peak power (up to 1 GW) millimeter-wave and submillimeter-wave emitters. Possible hazard levels associated with these systems cannot yet be adequately determined; they will require study when their operating characteristics are further defined.

MILLIMETER-WAVE BIOEFFECTS

Of the papers reviewed, 94 reports published between 1968 and 1979 inclusive are represented here. Eighty percent were published since 1974, indicating the growth in this area of RFR bioeffects research. A detailed review and analysis of each report has been documented under Air Force Contract F33615-79-C-0614 with the University of Utah, and the reader is referred to that report for detailed data. Only summarized results are presented in the paragraphs following and tabulated in Table I.

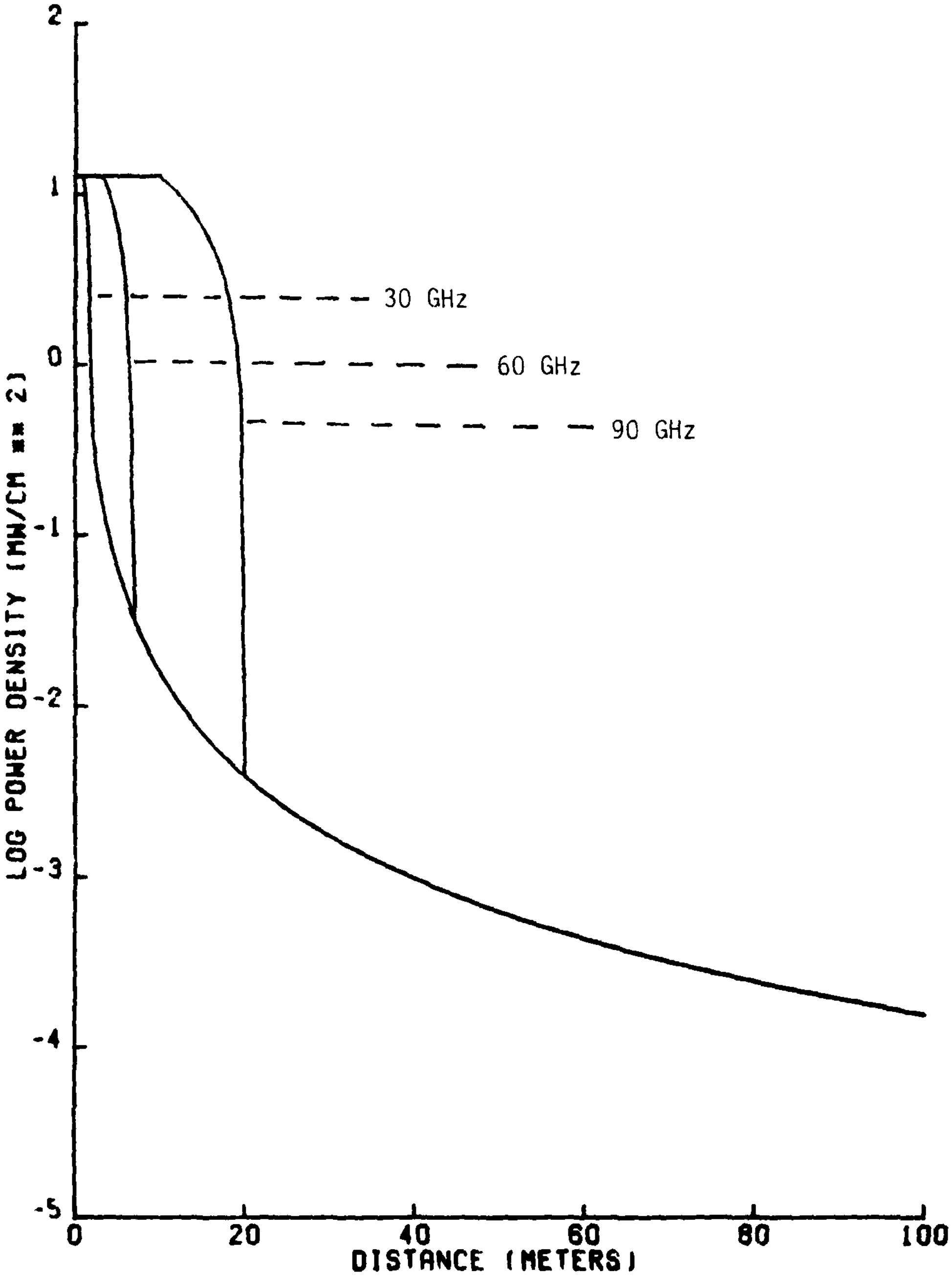

Figure 3. Log of power density versus distance for a 10-cm-diameter circular antenna with 1° beam width and 1-W output power.

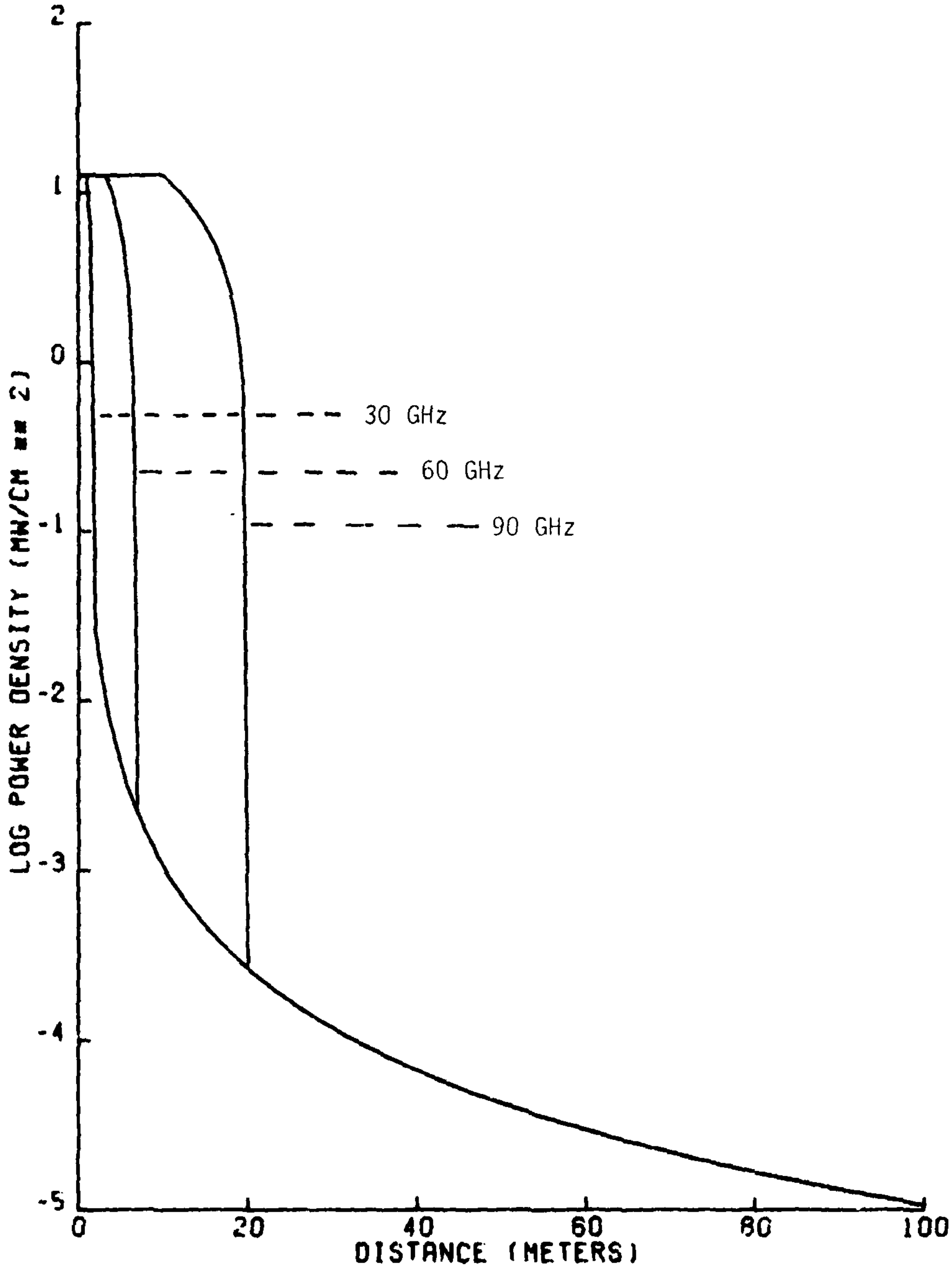

Figure 4. Log of power density versus distance for a 10-cm-diameter circular antenna with 6° beam width and 1-W output power.

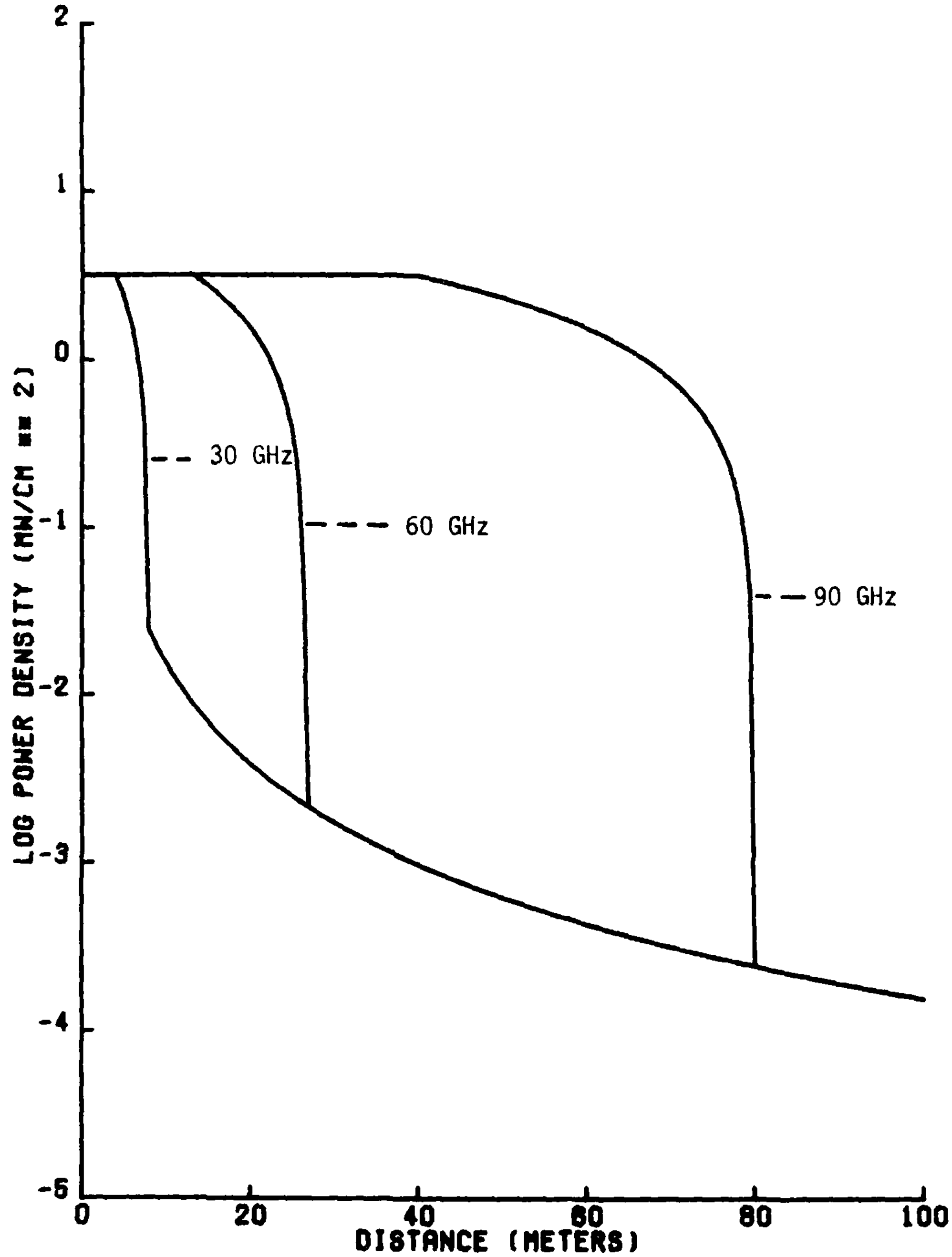

Figure 5. Log of power density versus distance for a 20-cm-diameter circular antenna with 1° beam width and 1-W output power.

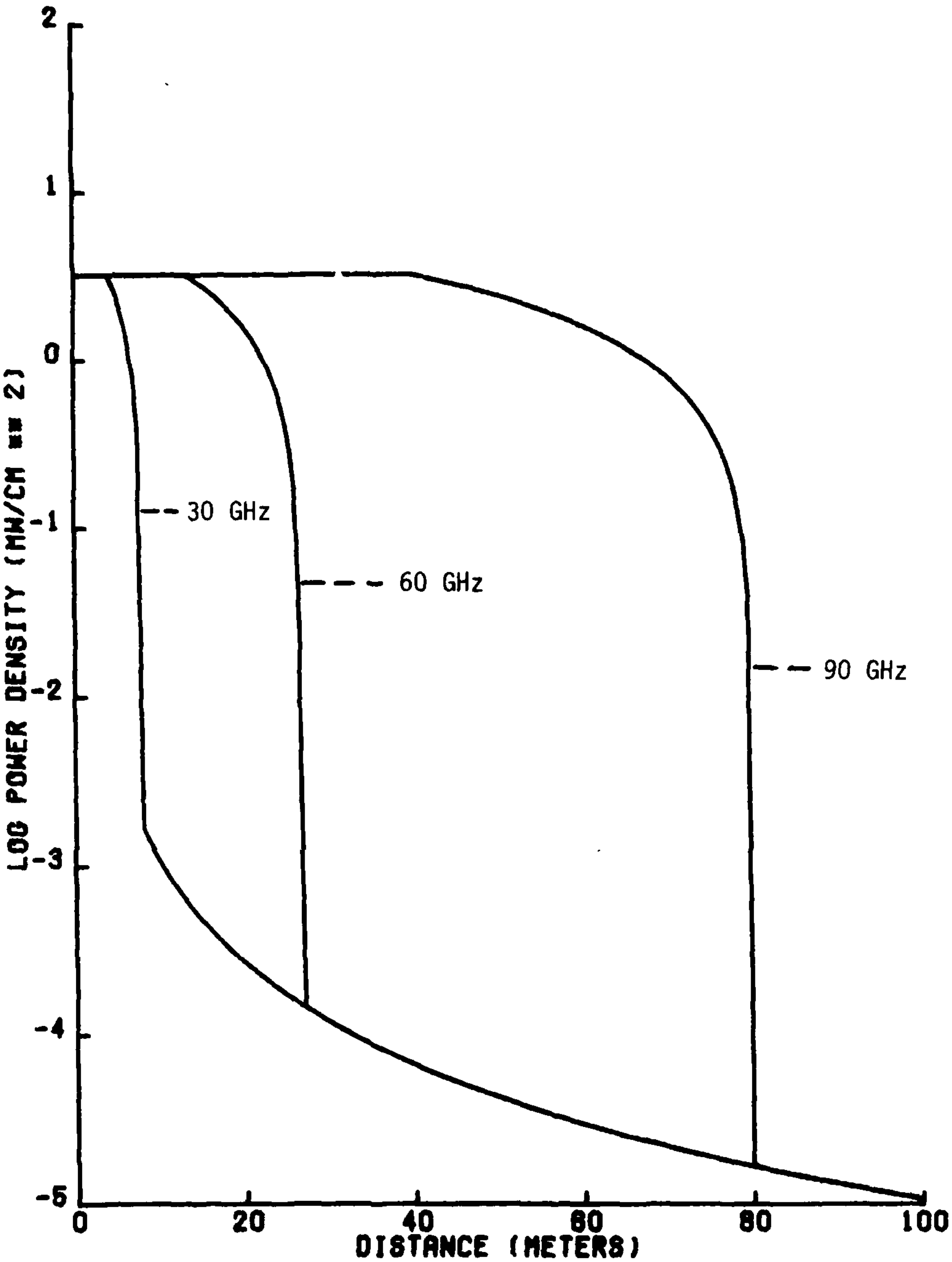

Figure 6. Log of power density versus distance for a 20-cm-diameter circular antenna with 6° beam width and 1-W output power.

TABLE 1. MILLIMETER-WAVE BIOEFFECTS REPORTS

Author, Year	Ref. No.	Biospecies	Freq. (GHz)	Intensity (mW/cm^2)	Effect(s)
Webb & Booth, 1969	1	Bact/Biochem	65-75	---	Cell growth
Webb & Booth, 1971	2	Cells/Biochem	66-76	---	Absorption measurements
Grundler et al., 1977	3	Bact	42	---	Cell growth
Devyatkov et al., 1974	4*	Bact	42	---	Cell growth
Berteaud et al., 1975	5	Bact/Biochem	70-75	∿10	Cell growth
Dardanoni et al., 1976	6	Bact	72	0.15	Cell growth
Webb & Dodds, 1968	7	Bact	136	0.007	Cell growth
Webb et al., 1977	8	Cells	65-95	20	Diagnosis
Hill et al., 1978	9	Bact	70-74	10	No changes
Swicord et al., 1978	10	Bact/Biochem	46	<1	Enzyme induction
Dardalhon et al., 1978	11	Bact	70-75	---	No effects
Gandhi et al., 1978	12	Cells/Bact/ Biochem	26-90	---	Dielectric properties
Dardanoni et al., 1978	13	Bact	72	---	Cell growth (pulsed only)
Webb, 1977	14	Bact/Cells 65-96	20	20	
Dardalhon et al., 1977	15	Drosophila	73	100	No effect
Gandhi et al., 1977	16	Cells/Bact/ Biochem	26-90	---	Dielectric properties
Grant, 1977	17	Biochem	1-100	---	Dielectric properties

*Russian journal

TABLE 1. (Continued)

Author, Year	Ref. No.	Biospecies	Freq. (GHz)	Intensity (mW/cm^2)	Effect(s)
Illinger, 1974	18	Theoretical		---	Effects unlikely
Edrich & Hardee, 1974	19	Instrumentation	---	---	Thermography
Sevastyanova & Vilenskaya, 1974	20*	Mouse	---	---	Bone marrow reaction
Edrich, 1975	21	Human skin	8-96	---	Absorption measurements
Edrich, 1975	22	Instrumentation	---	---	Thermography
Illinger, 1977	23	Theoretical	---	---	Attenuation functions
Antyukh et al., 1974	24*	Instrumentation	---	---	Microwave measurements
Webb & Stoneham, 1977	25	Bact	70-100	---	In-vivo oscillations
Webb et al., 1976	26	Cells	72	100	Cell metabolism (42°C)
Webb, 1974	27	Cells	59-143	---	Cell metabolism
Webb & Lee, 1977	28	Cells	65-95	---	Tumor vs normal cells
Tamburello & Zanfarlin	29	Cells	65-85	---	
Spalla et al., 1976	30	Instrumentation	---	---	
Sevastyanova & Potapov	31*	Animal	42	10	Selective hematological
Chernavskii, 1973	32*	Mechanisms	---	---	Speculations
Manoilov et al., 1974	33*	----------------No text------------------			
Klimov et al., 1974	34*	Instrumentation	---	---	Detectors

*Russian journal

TABLE 1. (Continued)

Author, Year	Ref. No.	Biospecies	Freq. (GHz)	Intensity (mW/cm^2)	Effect(s)
Edrich & Smyth, 1977	35	Instrumentation	---	---	Thermography of inflammatio
Zalyubovskaya et al., 1977	36*	Mitochondria	46	---	Metabolic effects
Bittner, 1975	37	Human	---	---	Hazard assessment (no text)
Sevastyanova et al., 1976	38*	Mouse	42	2.5	Protects marrow from X-ray
Zalyubovskaya, 1977	39*	Mouse, Human	37.5-60	1	Multiple, no date
Cherkasov et al., 1978	40*	Rabbit	---	---	Aid eye healing
Birenbaum et al., 1975	41	Rabbit	35, 107	5-50	Heat damage to eyes
Webb, 1975	42	Bact	59-143	10-50	Growth & metabolism
Zalyubovskaya et al., 1975	43	Cells	--------no text-------		
Kiselev & Zalyubovskaya, 1975	44	Cells	--------no text-------		
Zalyubovskaya & Kiselev, 1975	45	Cells	--------no text-------		
Zalyubovskaya & Kiselev, 1976	46	Cells	--------no text-------		
Bazanova et al., 1973	47*	Bact	42, 45	0.1	Aids wound healing
Sevastyanova & Vilenskaya, 1973	48*	Mouse	39-45	1-75	Protects marrow from X-ray
Smolyanskaya & Vilenskaya, 1973	49*	Bact	44-45	0.01+	Cell growth
Kondrat'eva et al., 1973	50*	Bact	42	---	Bacterial death

*Russian Journal

TABLE 1. (Continued)

Author, Year	Ref. No.	Biospecies	Freq. (GHz)	Intensity (mW/cm^2)	Effect(s)
Manoilov et al., 1973	51*	Bact	39-42	4-5	Cell growth & metabolism
Zalyubovskaya, 1973	52*	Bact, Insects, Chicks, Rats	46	---	Growth & heat effects
Gaiduk et al., 1973	54	Biochem	41	1	---no text---
Devyatkov et al., 1975	55*	Biochem	--------no text-------		
Kiselev & Zalyubovskaya, 1975	56*	Adenovirus	--------no text--------		
Ivanova & Chistyakova, 1975	57*	Bact	--------no text--------		
Edrich & Hardee, 1976	58	Muscle/Fat	40-54, 85-90	---	Permittivity measurements
Rosenthal et al., 1977	59	Rabbit	35, 107	15-50	Stromal injury
Birenbaum et al., 1974	60	Rabbit	35, 107	15-50	Stromal injury
Zalyubovskaya & Kiselev, 1978	61*	Cells	46	1	Growth effects, no thermal data
Zalyubovskaya & Kiselev, 1978	62*	Human, Mice	Mixed & 46	1	No objective effects reported
Grundler & Keilman, 1978	63	Yeast	42	50	Inconsistent growth effects
Croom et al., 1977	64	Instrumentation	35	---	Permittivity measurements
Gray & Buckmaster, 1973	65	Cells	34, 55	---	Biochemical changes
Vilenskaya, 1972	66*	Bact	37-52	1	Selective effects
Frohlich, 1979	67	Theoretical	---	---	Long-range CNS effects

*Russian journal

TABLE 1. (Continued)

Author, Year	Ref. No.	Biospecies	Freq. (GHz)	Intensity (mW/cm^2)	Effect(s)
Bigu-del-Blanco et al., 1975	68	Theoretical	---	---	Practical biostudies uses
Zalyubovskaya et al., 1975	69*	Cells	37.5-60	1	Protects frozen RBCs
Foster et al., 1978	70	Theoretical	---	---	Suggested research
Illinger, K., 1977	71	Theoretical	---	---	Possible resonances
Herschberger, 1978	72	Theoretical	---	---	Resonances may be artifact
Frohlich, 1968	73	Theoretical	---	---	Possible resonances
Frohlich, 1970	74	Theoretical	---	---	Possible resonances
Frohlich, 1975	75	Theoretical	---	---	Possible resonances
Frohlich, 1975	76	Theoretical	---	---	Possible resonances
Frohlich, 1978	77	Theoretical	---	---	Possible resonances
Zalyubovskaya, 1979	80*	Rat	---------no text-------		
Frohlich, 1977	81	Theoretical	---	---	Cites Russian work as support
Genzel et al., 1976	82	Biochem	Submillimeter	Resonances	
Webb et al., 1977	83	Bact	Raman shifts, submillimeter		
Cooper, 1978	84	Theoretical	---	---	Mimics Frohlich theory
Stamm et al., 1974	85	Cells	76-86	---	Difference between tumor and normal

*Russian journal

TABLE 1. (Continued)

Author, Year	Ref. No.	Biospecies	Freq. (GHz)	Intensity (mW/cm^2)	Effect(s)
Grant, 1968	86	Theoretical	---	---	Methods of dielectric, constant measurements
Slade & Farrow, 1972	87	Biochem	35, 70	---	Structural data on myoglobin
Djordjevic et al., 1979	88	Humans	300	1-5	No objective effects, syndrome due to working conditions
Athey & Krop, 1979	89	Bact	45.6-46.1	.1-10	No phage induction
Motzkin et al., 1979	90	Bact	50-75	0.5	No data, colicin induction
Melnick et al., 1979	91	Mitochondria	35, 50-60	500	No effects reported
Dardanoni et al., 1979	92	Bact	72-74	---	No data
Lee et al., 1979	93	Bact/Cells/ Biochem	26.5-90	---	Like water
Partlow et al., 1979	94	Cells	37-48, 65-75	177-292	No effects
Cain, 1979	95	Theoretical	---	---	Possible neural effects
Illinger, 1979	96	Theoretical	---	---	Possible Raman info

Summary of the Literature

<u>Cell-Culture Systems</u>--The largest group of studies deals with the effects of millimeter-wave RFR upon a diverse array of biological endpoints in cell-culture systems. Among the endpoints studied are cell growth, enzyme induction, phage induction, dielectric properties, cellular metabolism, and DNA and RNA synthesis. Effects are reported upon all of these parameters for cell types ranging from bacterial to mammalian. All reported effects have to be interpreted in light of the following considerations:

a) Effects reported can generally be attributed to changes known to occur upon elevation of temperature (e.g., changes in cell growth rate and metabolism).

b) Many of the reports demonstrate so-called "resonance" effects; that is, certain frequencies are preferentially absorbed, with the implication that these frequencies may be more hazardous. Hershberger (72) has challenged these resonance effects upon the basis of possible artifacts due to exposure geometry. Furthermore, these resonance phenomena are not replicable when proper attention is paid to factors such as impedance matching and reflections.

c) None of the reported effects appear to occur at cell-level intensities that would be encountered by personnel observing safety precautions in accordance with current guidelines.

d) Perhaps most important, none of the reported effects can be directly extrapolated to a human exposure. Many of the purported effects are observed in bacteria or other nonrelated organisms, and those in mammalian cells are subject to the difficulty of interpreting in-vitro results.

In summary, studies to date do not suggest millimeter waves as hazardous when confined to the levels at which no direct thermal insult occurs.

<u>Insects</u>--Two reports discussed possible genetic effects upon <u>Drosophila melanogaster</u>. No effects were seen at levels of exposure at or below the current safety guidelines.

<u>Animal Studies</u>--Effects of millimeter waves on animals again show only effects that would be expected for any frankly thermal insult; e.g., stress, behavioral changes, avoidance. However, none of these effects occur at any level of incident power density below current safety guidelines. One study of rabbit eyes exposed to mildly thermal doses of RFR at millimeter-wave frequencies showed that wound healing was aided and bacterial growth retarded (40). Comparison of possible damage by millimeter waves to that by infrared laser is useful. Corneal lesions can be caused by a 0.5-second exposure to 10.6-µm IR irradiation, with an ED50 power level of 4.71 Joules/cm^2. The equivalent millimeter-wave field intensity would correspond to about 9400 mW/cm^2 (79). High-power millimeter-wave systems might someday be capable of such hazards, and this should be considered during development, testing, and implementation of such systems.

Human Studies--Experimental studies in humans are limited to a few reports in the Eastern Bloc literature. These reports are anecdotal in nature, giving no experimental methods or details upon which to make biologic judgments and casting severe doubt upon the conclusions. The exception is a well-reported clinical study of radar workers by Djordjevic et al. (88) in which no objective findings could be produced to indicate an effect upon human health. The authors suggest that reports of microwave sickness or neurasthenic syndrome (a set of neurological and behavioral symptoms not directly measurable; such as headache, loss of memory, loss of sexual potency) should be attributed to other factors in the working environment; e.g., noise, having to watch a radar screen closely, and poor ventilation.

Western reports are limited to studies of skin penetration and support the discussion in the section "Penetration and Absorption in Humans."

Theory and Modeling--This is perhaps the second largest area of published reports and reflects an intensive search by many investigators to explore possible mechanisms of RFR interaction with living systems. These studies have attempted to project a linkage between millimeter waves and bioeffects at the molecular level. This work is severely hampered by the fact that there are very few effects, at any level, upon which to build theoretical models. Most such efforts cite the Eastern Bloc literature as support, which, as noted above, has a very loose foundation. To date, no replicable work has indicated a hazard at any level below frankly thermal intensities. However, several theories are still undergoing testing and will be watched for developments that might bear on safety considerations.

Modeling efforts have concentrated on predicting penetration depth and absorbed dose for superficial exposures, since whole-body absorbed doses are meaningless at MMW frequencies (78).

Penetration and Absorption in Humans

The penetration depth of an RF field in an absorber where the power has decayed to e^{-2} of the value at the surface is given by

$$\delta = \frac{67.52}{f} \left\{ \sqrt{(\varepsilon')^2 + (\varepsilon'')^2} - \varepsilon' \right\}^{-1/2}$$

where f is the frequency in MHz and ε' and ε'' are the real and imaginary parts of the relative permittivity. The values for the relative permittivity for frequencies up to 100 GHz were found in Durney et al. (78). For the penetration depth estimates at frequencies above 100 GHz, the relative permittivity value used was the same as that used for the 100-GHz value. The results of these calculations are presented in Table 2. Note that the maximum penetration depth occurs at a frequency of 30 GHz (the lowest frequency in the range) and is only 0.77 mm. This means that exposure to millimeter-wave RFR produces only a superficial exposure, similar to irradiation by infrared or visible light.

TABLE 2. CALCULATED PENETRATION DEPTH VALUES

Frequency GHz	Relative permittivities ε'	ε''	Penetration depth δ(cm)
30	18	19.5	.077
50	10.5	15	.048
90	6.15	9.15	.034
100	6	9.75	.029
130	6[a]	9.75[a]	.022[a]
150	6[a]	9.75[a]	.019[a]
220	6[a]	9.75[a]	.013[a]
240	6[a]	9.75[a]	.012[a]

[a]Used 100-GHz value of relative permittivity.

The decay formula applies only to a homogeneous medium in which the incident field is known. The real case is complicated by the fact that much of an incident beam at these frequencies would be reflected at the air/skin interface or by clothing. Succeeding tissue layers would also introduce reflections because of changes in the complex dielectric constants involved. The total attenuation, reflectance, and transmission of an incident beam cannot at this time be evaluated, but all these factors taken together would tend to increase the level of permissible exposure.

Summary by Frequency Range

Most of the reports we have reviewed to date were conducted at frequencies near 42 or 72 GHz. However, studies have been done over most of the frequency range between 30 and 143 GHz. The number of studies at each frequency is shown in Figure 7. Multiple use of certain frequencies or bands represents a combination of hardware limitations and multiple experiments from a few laboratories using an established set of hardware.

Thresholds and Significance

Thresholds for effects relevant to human exposure were mainly in the range 10-50 mW/cm^2 (15, 31, 41, 53, 59, 60) and were subject to the interpretive factors listed in the "Summary of the Literature" section. In sum, no effects are expected from exposures below current safety guidelines (10 mW/cm^2

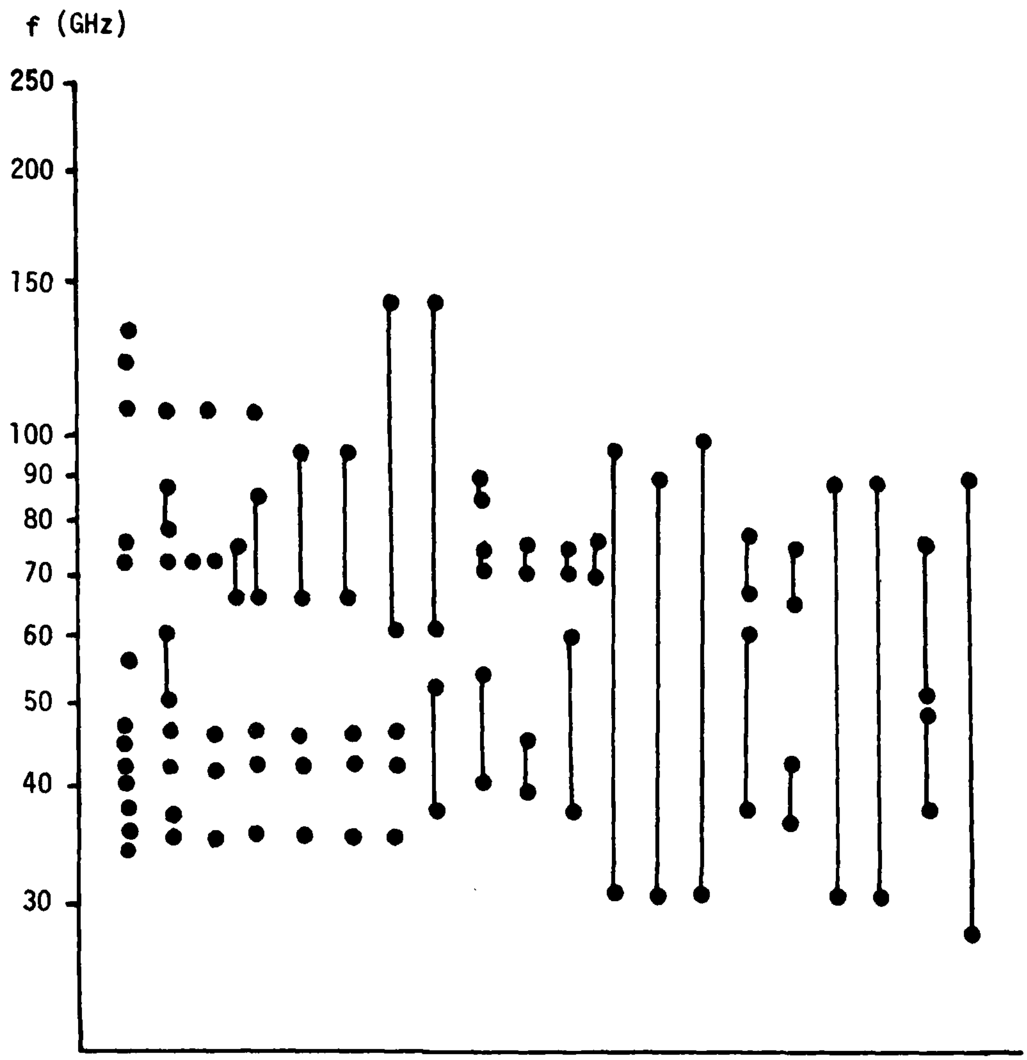

Figure 7. Occurrence of RFR studies reported here as a function of frequency. Each point represents a report, and each bar represents one report covering a range of frequencies.

or 3600 mW-sec/cm^2 in any 6-minute period). Any future revision of safety guidelines will probably be toward lower permissible exposures, thus further removing the possibility of hazard. Although effects upon cell systems were reported at levels somewhat lower than current safety guides, there is no evidence that these effects are harmful to humans. In some cases, the effects have been beneficial (38, 47, 48, 69). Futhermore cell-system effects must be extrapolated from nonthermoregulated in-vitro systems to in-vivo systems possessing thermoregulatory systems.

To date, no replicable results indicate any harmful effect upon organisms with exposures below current safety guidelines. No replicable effects have been demonstrated at any level except those directly or indirectly attributable to a thermal insult.

CURRENT SAFETY REGULATIONS

At present, all Air Force emitters of RF radiation (10 kHz to 300 GHz) are covered by the safety regulations in AFOSH Standard 161-9. For the millimeter-wave range, this standard requires that continuous exposure levels (greater than 6 minutes) be not greater than 10 mW/cm^2 and that, in any 6-minute period, the power density times the period of exposure be not greater than 3600 $mW\text{-}sec/cm^2$. Furthermore, the standard proscribes unnecessary exposures and requires that necessary exposures be held as low as practical.

DISCUSSION

Millimeter-wave bioeffects research is a comparatively young field, even when compared to RFR bioeffects. As such, it is subject to greater than the normal number of mistakes and misinterpretations. For example, a cavity-related series of peaks and valleys in an absorption curve can be misinterpreted as a "resonance" phenomenon in the biological sample. This type of error is encouraged by the multidisciplinary knowledge needed and by the lack of adequate experimental apparatus.

Several factors must be simultaneously controlled in this research, including absorbed dose and temperature regulation. Precautions against false-positive results must be extremely rigid and include instrumentation and exposure standards, proper controls (sham exposures), proper statistical reduction of data, and the input of basic biophysical data and theory.

The lack of one of the above experimental precautions, or necessities, accounts for the great number of nonreplicable results that appear in the MMW bioeffects literature. Although many effects have been reported, the only replicable effects supported by the body of reviewed literature are those due to frankly thermal insults to the organism.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of the bioeffects literature surveyed, no bioeffects basis is apparent upon which to differentiate millimeter-wave RFR from other frequencies. This conclusion implies that the same safety procedures should be considered for emitters of interest.

We recommend, therefore, that millimeter-wave systems be subjected to the analyses and safety procedures specified in AFOSH STD 161-9. Extreme care should be exercised around the transmitting antenna, its waveguide feed, and in the near field. In addition, confined test environments should be assessed for possible additive intensities due to scatter.

Experimental work is proceeding in several laboratories, and the Radiation Physics Branch, USAFSAM, will maintain a watch over this new technology. As new, higher power hardware becomes available, the possibility of a high-intensity exposure, especially to exposed skin surfaces, such as the ears, eyes, and hands, may increase. Adequate modeling of exposed tissues must rely on a data base of dielectric constants, reflection coefficients, and heat-dissipative mechanisms. USAFSAM will maintain special interest in these areas as part of the overall technology watch.

REFERENCES

1. Webb, S. J., and A. D. Booth. Absorption of microwaves by microorganisms. Nature 222:1199-1200 (1969).

2. Webb, S. J., and A. D. Booth. Microwave absorption by normal and cancer cells. Science 174:72-74 (1971).

3. Grundler, W., et al. Resonant growth rate response of yeast cells irradiated by weak microwaves. Phys Lett 62A:463-466 (1977).

4. Devyatkov, N. D., et al. Influence of millimeter-band electromagnetic radiation on biological objects. Sov Phys-Uspekhi 16(4):568-579 (1974).

5. Berteaud, A. J., et al. Effects of electromagnetic radiation of millimetric wavelength on bacterial growth. C R Acad Sci [D] (Paris) 281: 843-846 (1975).

6. Dardanoni, L., et al. Biological effects of millimeter waves at spectral singularities. Third Symposium on Electromagnetic Compatibility, Wroclaw, Poland, 1976.

7. Webb, S. J., and D. D. Dodds. Inhibition of bacterial cell growth by 136 GHz microwaves. Nature 218:374-375 (1968).

8. Webb, S. J., et al. Possible viral involvement in human mammary carcinoma; a microwave and laser-Raman study. Int J Quantum Chem; Quantum Biology Symposium 4, 227-284 (1977).

9. Hill, D. W., et al. Effects of millimeter waves on bacteria and viruses. 19th General Assembly, URSI, Helsinki, 1978.

10. Swicord, M. L., et al. Colicin induction by exposure to millimeter-wave radiation. 19th General Assembly, URSI, Helsinki, 1978.

11. Dardalhon, M., et al. Effects of millimeter waves on bacteria and yeast. 19th General Assembly, URSI, Helsinki, 1978.

12. Gandhi, O. P., et al. Millimeter wave absorption spectra of living tissue. 19th General Assembly, URSI, Helsinki, 1978.

13. Dardanoni, L., et al. Biological effects of 72-GHz microwaves on *C. albicans* cells. 19th General Assembly, URSI, Helsinki, 1978.

14. Webb, S. J. Possible detection of in-vivo latent viruses in tumor and bacterial cells and their induction by millimeter microwaves. Presented at International Symposium on Biological Effects of Electromagnetic Waves, Airlie, Va., 1977.

15. Dardalhon, M., et al. Microwave effects in *Drosophila melanogaster*. Presented at International Symposium on Biological Effects of Electromagnetic Waves, Airlie, Va., 1977.

16. Gandhi, O. P., et al. Effects of millimeter waves on living tissue. Presented at International Symposium on Biological Effects of Electromagnetic Waves, Airlie, Va., 1977.

17. Grant, E. H. Measurement of the electrical properties of biological liquids at frequencies between 1 and 100 GHz. Presented at International Symposium on Biological Effects of Electromagnetic Waves, Airlie, Va., 1977.

18. Illinger, K. H. Interaction between microwave and millimeter-wave EM fields and biologic systems: Molecular mechanisms. In P. Czerski et al. (Eds.). Biological effects and health hazards of microwave radiation, 160-172. Polish Medical Publishers, 1974.

19. Edrich, J., and P. C. Hardee. Thermography at millimeter wave lengths. Proc IEEE 62:1391-1392 (1974).

20. Sevastyanova, L. A., and R. L. Vilenskaya. Mouse bone marrow reaction to altered UHF millimeter irradiation parametric variation. Biol Nauki 6:48-50 (1974). Transl. in JPRS 64532.

21. Edrich, J. Microwave absorption of living human skin between 8 and 96 GHz. Proc 5th European Microwave Conference, Hamburg, Sep 1975. Paper 6-1.

22. Edrich, J. Thermographic imaging at millimeter and centimeter wave lengths. Proc Conference on Application of Optical Instrumentation in Med, IV. Atlanta, Sep 1975. Paper MQ-155.

23. Illinger, K. H. The attenuation function for biological fluids at millimeter and far-infrared wavelengths. In C. C. Johnson and M. L. Shore (Eds.). Biological effects of EM waves, Vol. II, 169-183, HEW Publication (FDA) 77-8011, 1977.

24. Antyukh, Ye. V., et al. Detection of millimeter and submillimeter emission by means of Josephson junctions. Abstract, Referativnyy Zh, Radiotekhnika, No. 6: Abstract No. 6YE314, 1974. Transl. in JPRS 64532.

25. Webb, S. J., and M. E. Stoneham. Resonances between 10^{11} and 10^{12} Hz in active bacterial cells as seen by laser Raman spectroscopy. Phys Lett 60A (3):267-268 (1977).

26. Webb, S. J., et al. Effects of microwaves on the metabolic time clocks of normal and tumour cells: A laser-Raman study. IRCS Med Sci 4:10 (1976).

27. Webb, S. J. Nutrition, metabolic time sequences and in-vivo unidirectional motions, III. The absorption and effects of microwave radiation. IRCS Res Biochem 2:1229 (1974).

28. Webb, S. J., and R. Lee. Microwave and laser-Raman spectra of normal and tumor human mammary tissue. IRCS Med Sci 5:102 (1977).

29. Tamburello, C. C., and L. Zanfarlin. Millimeter wave irradiation and measurement system for cell suspensions. (From Dr. O. P. Gandhi, unreferenced preprint)

30. Spalla, M., et al. A method to measure the characteristics of biological materials at millimeter waves. 6th European Microwave Conference, 1976.

31. Sevastyanova, L. A., and S. L. Potapov. Resonance effects in biological action of microwave radiation. (From Dr. O. P. Gandhi, unreferenced preprint)

32. Chernavskii, D. S. Remarks on two possible mechanisms of the effect of microwaves on hemoglobin. Sov Phys-Uspekhi 16(4):577-578 (1974). Transl. from Usp Fiziot Nauk 110, Issue N3, 1973.

33. Manoilov, S. E., et al. Possibility of using EMRs of the millimeter wavelength to intensify the biological properties of blood proteins. Abstract, Referativnyy Zh, Biol, No. 11 (II): Abstract No. 11N77, 1974. Transl. in JPRS 64532.

34. Klimov, B. N., et al. Utilizing nonlinear properties of semiconductors which show up in strong electric fields for detecting emission in the millimeter and submillimeter bands. Abstract, Referativnyy Zh, Radio tekknika, No. 6: Abstract No. 6D59, 1974. Transl. in JPRS 64532.

35. Edrich, J., and C. J. Smyth. Millimeter wave thermograph as subcutaneous indicator of joint inflammation. Abstract, 7th European Microwave Conference, Book of Abstracts, 71. Copenhagen, Sep 1977.

36. Zalyubovskaya, N. P., et al. Effects of EM waves of the millimetric range on the energy metabolism of liver mitochondria. Biol Nauki 6:133-134 (1977). Transl. in JPRS 70101.

37. Bittner, I. G. Hazards to persons from alternating EM fields in the frequency range of 3 kHz to 3,000 GHz. Biomed Tech (Berlin) 20:159 (1975).

38. Sevastyanova, L. A., et al. Characteristics of millimeter wave effects in combination with fluorafure on the hemopoietic system. Biol Nauki 12:27-31 (1976). Transl. in JPRS L/6983.

39. Zalyubovskaya, N. P. Biological effect of millimeter radiowaves. Vrach Delo 3:116-119 (1977). Transl. in JPRS L/7298.

40. Cherkasov, I. S., et al. Biomedical effects of millimeter radio waves. Oftalmol 3:187-190 (1978). Transl. in JPRS 71910.

41. Birenbaum, L., et al. Ocular effects of 35 and 107 GHz CW microwaves. Proc Microwave Power Symposium, May 28-30, 1975. Univ. of Waterloo, Ontario, Canada, pp. 105-110.

42. Webb, S. J. Genetic continuity and metabolic regulation as seen by the effects of various microwave and black light frequencies on these phenomena. Ann NY Acad Sci 247:327-351 (1975).

43. Zalyubovskaya, N. P., et al. Reactions of red blood cells to SHF radiation in the millimeter range. Eksp Klin Radiol Resp., Mezhued sb, Kiev, 2:75-79 (1975).

44. Kiselev, R. I., and N. P. Zalyubovskaya. Immunobiological reactions in response to superhigh frequency electromagnetic fields in the millimeter range. Immunol Allerg, Mezhued sb (Immunology and Allergy, Interdepartmental Collection), Kiev, 9:23 (1975).

45. Zalyubovskaya, N. P., and R. I. Kiselev. Electric microscopic investigation of the reaction of tissue culture cells to electromagnetic waves in the millimeter range. Primen Elektr Mikrosk Materialoved Biol Med (tez, dokl) (Application of Electric Microscopy in Materials Science, Biology and Medicine) (Report Abstracts), Kiev, 2:14-15 (1975).

46. Zalyubovskaya, N. P., and R. I. Kiselev. Change in biochemical and biophysical properties of tissue culture cells infected by adenovirus irradiated by millimeter waves of superhigh frequency and athermal intensity. Virusy Virusn Zabol, Rep Mezhued sb. (Viruses and Virial Diseases, Republic Interdepartmental Collection), Kiev, 4:71-72 (1976).

47. Bazanova, E. B., et al. Certain methodological problems and results of experimental investigation effects of microwaves on microorganisms and animals. Sov Phys-Uspekhi 16(4):569-570 (1974). Transl. from Usp Fiziol Nauk 110:452-469 (1973).

48. Sevastyanova, L. A., and R. L. Vilenskaya. A study of the effects of millimeter-band microwaves on the bone marrow of mice. Sov Phys-Uspekhi 16(4):570-571 (1974). Transl. from Usp Fiziol Nauk 110, Issue N3 (1973).

49. Smolyanskaya, A. Z., and R. L. Vilenskaya. Effects of millimeter-band electromagnetic radiation on the functional activity of certain genetic elements of bacterial cells. Sov Phys-Uspekhi 16(4):571-572 (1974). Transl. from Usp Fiziol Nauk 110, Issue N3 (1973).

50. Kondrat'eva, V. F., et al. Effects of millimeter-band radio waves on certain properties of bacteria. Soviet Phys-Uspekhi 16 (4):572-573 (1974). Transl. from Usp Fiziol Nauk 110, Issue N3 (1973).

51. Manoilov, S. E., et al. Effects of millimeter-band electromagnetic waves on certain aspects of protein metabolism in bacteria. Sov Phys-Uspekhi 16(4):573-574 (1974).

52. Zalyubovskaya, N. P. Reactions of living organisms to exposure to millimeter-band electromagnetic waves. Sov Phys-Uspekhi 16(4):574-576 (1974).

53. Kiselev, R. I., and N. P. Zalyubovskaya. Effects of millimeter-band electromagnetic waves in the cell and certain structural elements of the cell. Sov Phys-Uspekhi 16(4):576-577 (1974).

54. Gaiduk, V. I., et al. Outlook for study of the mechanisms of the non-thermal effects of millimeter- and submillimeter-band electromagnetic radiation on biologically active compounds. Sov Phys-Uspekhi 16(4): 577-578 (1974).

55. Devyatkov, N. D., et al. Effect of low-intensity millimeter radiation on gammaresonance spectrums of hemoglobin. Dokl Akad Nauk SSSR 225:962-965 (1975). Transl. in JPRS L/5787.

56. Kiselev, R. I., and N. P. Zalyubovskaya. Study of the inhibiting effect of superhigh frequency millimeter waves on adenovirus. Vopr Virusol 5:617-620 (1975). Transl. in JPRS L/5615.

57. Ivanova, N. B., and Ye. N. Chistyakova. Action of electromagnetic radiation in the millimeter wavelength range on certain properties of micro-organisms. In "Fiz.-mat. i bio. probl. deystviya EMP i ionizatsii v-kha." Vsesoyuz. n/t simpoz. g. Yalta, 25027 n. 1975 g., Moscow, Izdvo Nauka 2:122-123 (1975).

58. Edrich, J., and P. C. Hardee. Complex permittivity and penetration depth of muscle and fat tissues between 40 and 90 GHz. IEEE Trans MTT-24:273-275 (1976).

59. Rosenthal, S. W., et al. Effects of 35- and 107-GHz CW microwaves on the rabbit eye. In C. C. Johnson and M. L. Shore (Eds.). Biological effects of EM waves, Vol. I, 110-128. HEW Pub. (FDA) 77-8010, 1977.

60. Birenbaum, L., et al. Ocular effects of 35- and 107-GHz CW microwaves. Report R-452.39-74 (Nov. 1974) to Joint Serv. Tech. Adv. Comm. AFOSR-TR-74-1922, 140-145.

61. Zalyubovskaya, N. P., and R. I. Kiselev. Biological oxidation in cells exposed to microwaves in the millimeter range. Tsitol Genet 12(3):232-236 (1978).

62. Zalyubovskaya, M. P., and R. I. Kiselev. Effect of millimeter-range radio waves on the human and animal body. Gig Sanit 8:35-39 (1978).

63. Grundler, W., and F. Keilman. Nonthermal effects of millimeter micro-waves on yeast growth. Z Naturforsch [C] 33(1-2):15-22 (1978).

64. Croom, E. J., et al. Dielectric dispersion of DL-alpha-valine in aqueous solution. J Microwave Power 12(2):111-117 (1977).

65. Gray, A. L., and H. A. Buckmaster. Electron paramagnetic resonance (34 and 55 GHz) studies of hemoproteins. Can J Biochem 51(8):1142-1153 (1973).

66. Vilenskaya, R. L., et al. Induction of colicin synthesis by millimeter radiation. Biull Eksp Biol Med 73(4):52-54 (1972).

67. Frohlich, H. Possibilities of long- and short-range electric interactions of biological systems. Neurosci Res Program Bull 15:67-72 (1979).

68. Bigu-del-Blanco, J., et al. Microwave radiometry and its potential applications in biology and medicine: Experimental studies. Biotelemetry 2:298-316 (1975).

69. Zalyubovskaya, N. P., et al. Action of electromagnetic fields of superhigh frequencies on erythrocytes preserved at low temperature. Probl Gematol Pereliv Krovi 20:31-33 (1975). Transl. in JPRS 66512.

70. Foster, K. R., et al. Effect of surface cooling and blood flow on the microwave heating of tissue. IEEE Trans BME-25:313-316 (1978).

71. Illinger, K. Millimeter wave and far-infrared absorption in biological systems. In L. S. Taylor and A. Y. Cheung (Eds.). The physical basis of electromagnetic interactions with biological systems. Proc Workshop held at Univ. of Maryland, College Park, 15-17 June 1977.

72. Hershberger, W. D. Microwave transmission through normal and tumor cells. IEEE Trans MTT-8:618-619 (1978).

73. Frohlich, H. Long-range coherence and energy storage in biological systems. J Quant Chem 2:641-649 (1968).

74. Frohlich, H. Long-range coherence and the action of enzymes. Nature 228:1093 (1970).

75. Frohlich, H. Evidence for bose condensation-like excitation of coherent modes in biological systems. Phys Lett 51A (1):21-22 (1975).

76. Frohlich, H. The extraordinary dielectric properties of biological materials and the action of enzymes. Proc Natl Acad Sci USA, 72(11): 4211-4215 (1975).

77. Frohlich, H. Coherent electric vibrations in biological systems and the cancer problem. IEEE Trans MTT-26(8):613-617 (1978).

78. Durney, C. H., et al. Radiofrequency radiation dosimetry handbook (second edition). SAM-TR-78-22, May 1978, p. 61. (Available from Mr. Stewart Allen, USAFSAM/RZP, Brooks AFB TX 78235)

79. Mikesell, G. W., Jr., et al. Lesion duration and curvature change in the cornea following exposure to a carbon dioxide laser. SAM-TR-79-26, Oct 1979.

80. Zalyubovskaya, N. P. Effects of millimeter radio waves on the neurohumoral system in rats. Biol Nauki 2:107 (1979) (JPRS 73777, 28 June 1979).

81. Frohlich, H. Coherent excitations in biological systems. Biofizika 22:743-744 (1977).

82. Genzel, L., et al. Low-frequency Raman spectra of lysozyme. Biopolymers 15:219-225 (1976).

83. Webb, S. J., et al. Evidence for non-thermal excitation of energy levels in active biological systems. Phys Lett 63A:407-408 (1977).

84. Cooper, M. S. Long-range coherence and cancer. Phys Lett 65A:71-73 (1978).

85. Stamm, M. E., et al. Microwave characteristics of human tumor cells. Oncology 29:294-301 (1974).

86. Grant, E. H. The study of biological molecules by dielectric methods (ch 9). In S. J. Wyard (Ed.). Solid state biophysics. New York: McGraw-Hill Book Co., 1968.

87. Slade, E. F., and R. H. Farrow. Millimeter wave EPR studies of some high spin myoglobin derivatives. BBA 278:450-458 (1972).

88. Djordjevic, Z., et al. A study of the health status of radar workers. Aviat Space Environ Med 50:396-398 (1979).

89. Athey, T. W., and B. A. Krop. Millimeter-wave radiation fails to induce lambda phage expression. BEMS Symposium, Seattle, Wash., 18-22 June 1979, p. 458.

90. Motzkin, S., et al. Millimeter wave CW cells irradiation studies. I: microwave aspects. Colicin induction in *E. coli*. BEMS Symposium, Seattle, Wash., 18-22 June 1979, p. 460.

91. Melnick, R., et al. Millimeter wave CW cells irradiation studies. II: Membrane transport in mitochondria and erythrocytes. BEMS Symposium, Seattle, Wash., 18-22 June 1979, p. 461.

92. Dardanoni, L., et al. Sensitivity of *C. albicans* cells to frequency of modulation in the 72-74-GHz band. BEMS Symposium, Seattle, Wash., 18-22 June 1979, p. 462.

93. Lee, R. A., et al. Millimeter wave absorption spectra of biological samples. BEMS Symposium, Seattle, Wash., 18-22 June 1979, p. 463.

94. Partlow, L. M., et al. A search for frequency-specific bioeffects caused by microwave irradiation. BEMS Symposium, Seattle, Wash., 18-22 June 1979, p. 464.

95. Cain, C. A. A theoretical basis for microwave and RF field effects on excitable cellular membranes. BEMS Symposium, Seattle, Wash., 18-22 June 1979, p. 466.

96. Illinger, K. H. Vibrational spectra of in-vivo biological systems. BEMS Symposium, Seattle, Wash., 18-22 June 1979, p. 467.

97. Satinoff, E. Neural orgarization and evolution of thermal regulation in mammals. Science 201:16-22, 1978.

APPENDIX A. COMPUTER PROGRAMS

Two computer programs were written to run on the USAFSAM PDP-11/70 computer system. These programs are in the BASIC language, so with minimal modifications they should run on any similar computer.

Each program accepts terminal inputs for antenna size, average output power, beam width, and wavelength. The first program, PDENS, computes and prints the distances from the antenna at which power densities of 10, 1, and 0.1 mW/cm^2 would be expected, based upon the model presented in the section "Characteristics of Model System."

The second program, MMPLOT, goes further. After accepting the terminal inputs, it computes an array of distances, corresponding power densities, and the common log of the power densities, and stores them in a user-named data file. This "virtual array" file may then be used by the computer system as input data to STAT-11 (or SAMSTAT, the USAFSAM modified version of STAT-11) for purposes of analysis and construction of plots.

The model does not incorporate antenna gain, so average output power should be entered by the user after modification by the gain figure. The model also does not incorporate near-field corrections, but rather gives a worst-case envelope within which some fluctuations should be anticipated.

PDENS.B2S

```
10 REM BASIC PROGRAM TO COMPUTE THE 10, 1, AND 0.1 MW/SQ.CM. POINTS
20 REM FOR A GIVEN MM WAVE SYSTEM.  WRITTEN BY DAVID N. ERWIN.
30 PRINT 'MM WAVE SELECTED POWER DENSITY DISTANCES.'
40 PRINT \ INPUT 'DO YOU WANT TO RUN THE PROGRAM (Y/N)';A$
50 IF LEFT(A$,1%)="Y" THEN 55 ELSE 900
55 L=LA=TH=W=0
60 PRINT \ INPUT 'ANTENNA DIAMETER L(CM)=';L
70 INPUT 'ANTENNA DISPERSION ANGLE THETA(DEGREES)=';TH
80 INPUT 'WAVELENGTH LAMBDA(MM)=';LA
90 INPUT 'AVE. POWER OUTPUT(WATTS)=';WW \ W=WW*1000
95 PRINT \ PRINT
100 NF=(.1*L↑2)/LA \ PRINT 'NEAR FIELD POINT=';NF;'METERS'
110 F=2*NF \ PRINT 'FAR FIELD POINT=';F;'METERS'
120 PN=W/(PI*(L/2)↑2) \ X=10  \T=TAN(TH/2)
130 PF=W*1.0E-04/(PI*(F*T)↑2) \ F1=W*LA*10*((LA↑2/(400*(L*T)↑2))-4)/(PI*L↑4)
135 PRINT \ PRINT
140 IF  X>PN  THEN GOTO 400
150 IF  X>PF  THEN D=((X-PN)/F1)+NF ELSE 160 \ GOTO 500
160 D=SQR(W/(PI*X*1.0E04*T↑2)) \ GOTO 500
400 PRINT 'POWER DENSITY LEVEL';X;'MW/SQ.CM. IS INTERNAL TO THE SYSTEM'
410 X=X/10 \ IF X<=.01 THEN 40 ELSE GOTO 140
500 PRINT 'POWER DENSITY LEVEL';X;'MW/SQ.CM. IS AT';D;'METERS'
510 X=X/10 \ IF X<=.01 THEN 40 ELSE GOTO 150
900 PRINT 'ADIOS AMIGO'\END
```

MMPLOT.B2S

```
10 PRINT 'BASIC+2 PROGRAM RUNS ON PDP-11/70 UNDER RSX-11M'
15 PRINT \ PRINT 'THIS PROGRAM ACCEPTS MILLIMETER WAVE SYSTEM PARAMETERS'
20 PRINT 'FROM THE TERMINAL AND COMPUTES AN ARRAY OF DISTANCES AND'
25 PRINT 'POWER DENSITIES PASSED TO THE SAMSTAT PLOTTING PACKAGE.'
30 PRINT \ PRINT ! REENTRY POINT FOR ADDED RUNS
35 INPUT 'ANTENNA DIAMETER L(CM)=';L
40 INPUT 'ANTENNA DISPERSION ANGLE THETA(DEGREES)=';TH
45 INPUT 'WAVELENGTH LAMBDA(MM)=';LA
50 INPUT 'AVE. POWER OUTPUT(WATTS)';WW \ W=WW*1000
55 PRINT \ PRINT
60 REM NEAR-FIELD & FAR-FIELD POINT CALCULATIONS
65 NF=.1*L^2/LA \ PRINT 'NEAR FIELD POINT=';NF;'METERS'
70 F=2*NF \ PRINT 'FAR FIELD POINT=';F;'METERS'
71 XX=2*(INT(NF)+1)
75 REM SETTING UP THE OUTPUT FILE
80 DIMENSION #1, S(250,15)
85 PRINT 'NAME THE OUTPUT FILE' \ INPUT A$
90 OPEN A$ FOR OUTPUT AS FILE 1, VIRTUAL, ALLOW MODIFY
95 MAT S=ZER
97 S(1,0)=3
98 PN=W/(PI*(L/2)^2)
99 LET D=0 \ PD=PN
100 FOR I=1 TO XX
110 S(I,1)=D \ S(I,2)=PD \ D=D+0.5
120 IF D>NF THEN 130
125 NEXT I
130 T=TAN(TH/2) \ F1=W*LA*10*((LA^2/(400*(L*T)^2))-4)/(PI*L^4)
135 FOR J=1 TO XX
140 PD=F1*D-F1*NF+PN \ S(I+J,1)=D \ S(I+J,2)=PD
145 D=D+0.5
150 IF D>F THEN 160 ELSE 155
155 IF D>100 THEN 500 ELSE 156
156 NEXT J
160 FOR K=1 TO 200
165 PD=W*1.0E-04/(PI*(D*T)^2) \ S(I+J+K,1)=D \ S(I+J+K,2)=PD
170 D=D+0.5
171 IF D>100 THEN 500
175 NEXT K
500 PRINT 'END OF RUN' \PRINT
505 PRINT 'MATRIX  ' ;A$;'   CONTAINS THE FOLLOWING POINTS' \ PRINT
510 PRINT 'NEAR FIELD-';I;' TRANSITION-';J;' FAR FIELD-';K \ PRINT
515 X=I+J+K \ PRINT 'FOR A TOTAL OF ';X;'POINTS'
520 FOR B=0 TO 3 \ S(0,B)=X \ NEXT B
525 INPUT 'DO YOU WANT TO PRINT THE MATRIX';G$
530 FOR X3=1 TO X \ S(X3,3)=LOG10(S(X3,2)) \ NEXT X3
535 IF LEFT (G$,1%)="Y" THEN 540 ELSE 550
540 FOR X2=1 TO X \ PRINT S(X2,1),S(X2,2),S(X2,3) \ NEXT X2
550 CLOSE #1
600 INPUT 'WANT ANOTHER RUN';F$
630 IF LEFT(F$,1%)="Y" THEN 30 ELSE 900
900 PRINT \ PRINT 'MMPLOT SIGNED OFF' \ END
```

DAT
FILM